M³ Overview and Working with M³ Data

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M³ Data Tutorial at LPSC

March, 2011

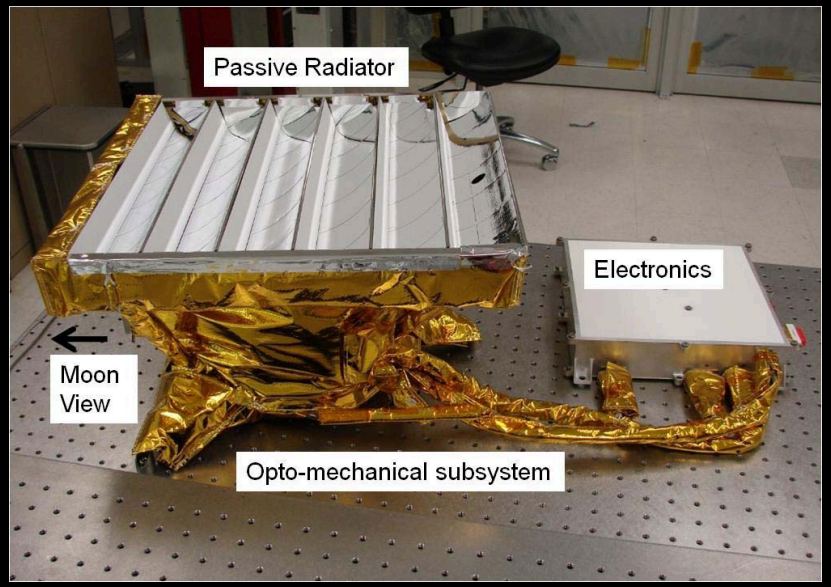
Topics to be discussed

- Instrument overview
- M^3 observation history
- Dataset description
- Calibration pipeline
- Dataset and R4 calibration issues
- Converting radiance to I/F with ENVI

For Reference

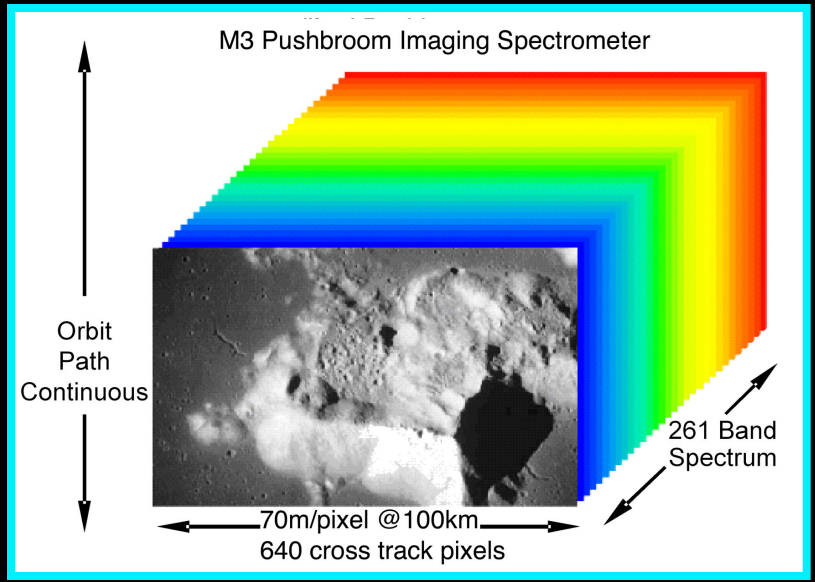
- Slides and example data from this workshop available at: http://m3.jpl.nasa.gov/m3data.html
- References for more complete description of these topics:
  - Green et al. (JGR, Under Review)
  - Boardman et al. (JGR, In Press)
  - Clark et al. (JGR, In Press)

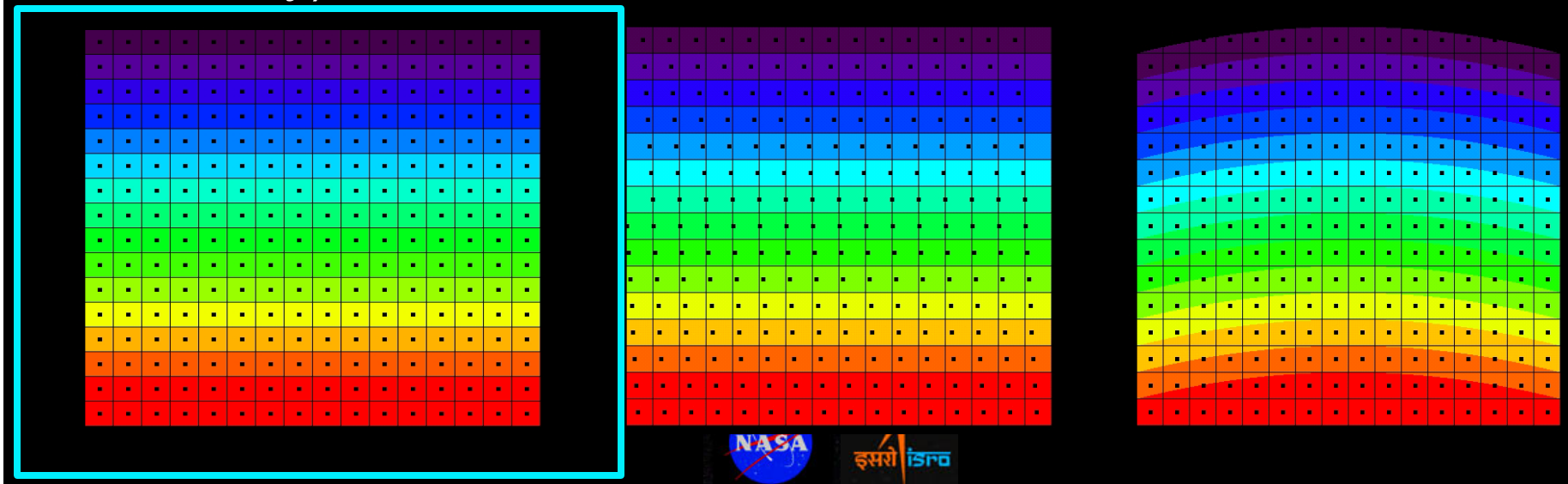
M^3 Instrument



Instrument Design

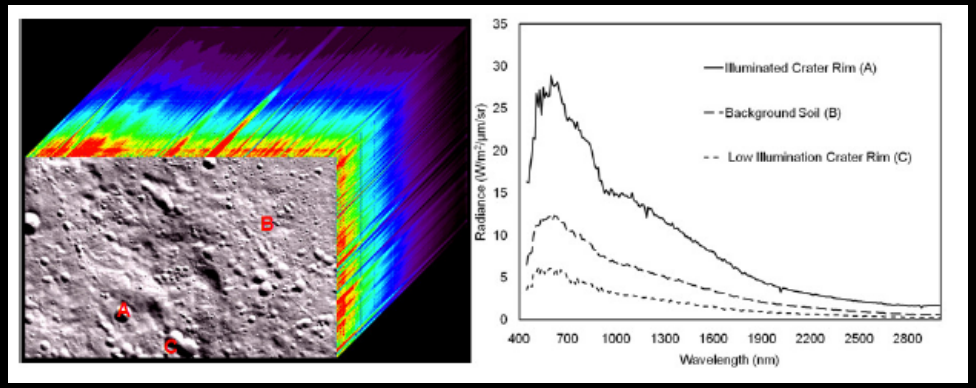
- Pushbroom imaging spectrometer
  - Each detector readout is 1 line of an image cube. The entire image is built as M3 moves along the ground track.
- High Spectral/Spatial Uniformity (>90% spectral crosstrack and spectral IFOV uniformity)

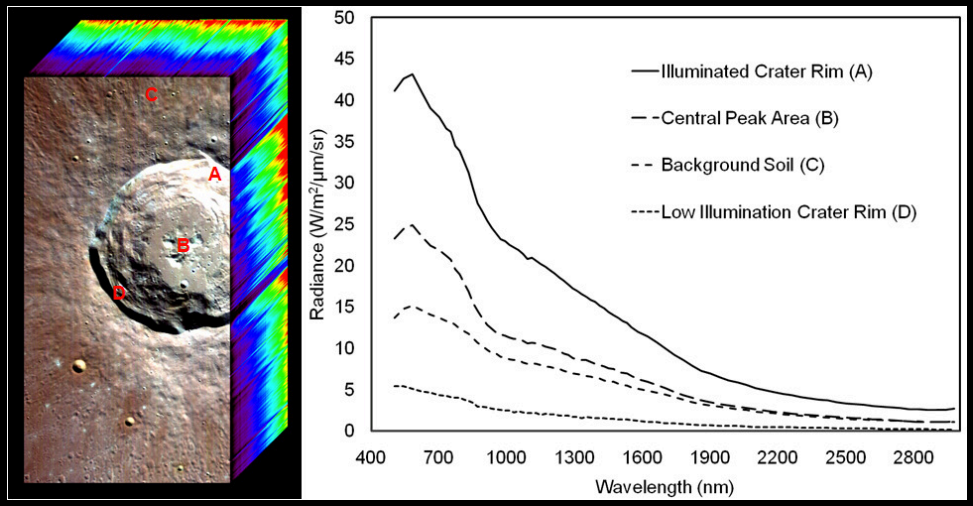




Operational Modes

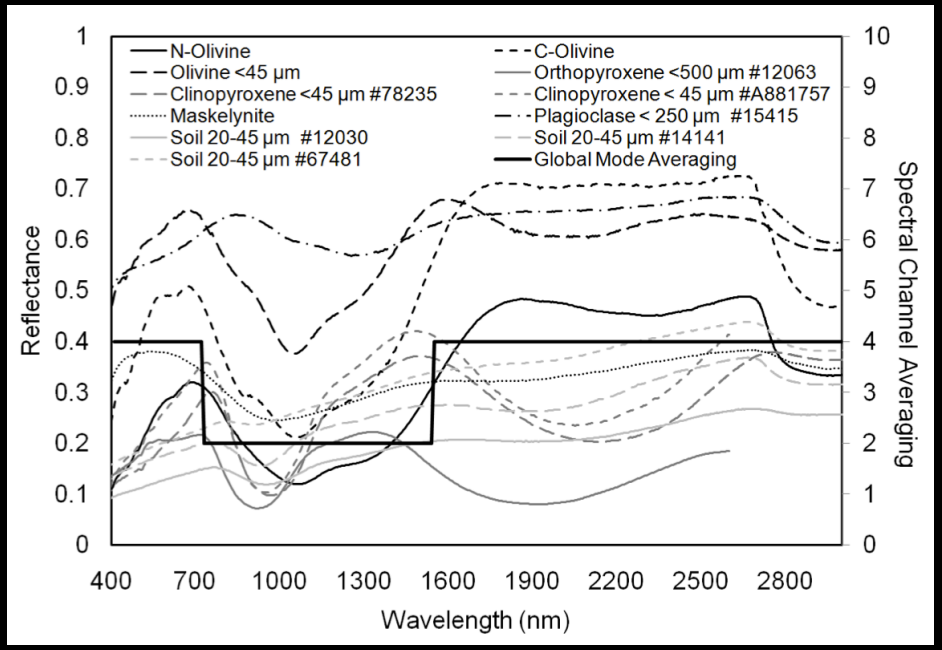
- Target
  - High spatial/spectral resolution mode for priority observations
  - Only a few target observations were actually acquired
- Global
  - M3 instrument acquires full resolution data then onboard software averages data to produce reduced resolution data
  - Lower resolution (spatial & spectral) mode for mapping the entire Moon
  - *Majority of the M3 data set is global data*





Spatial and Spectral Resolution

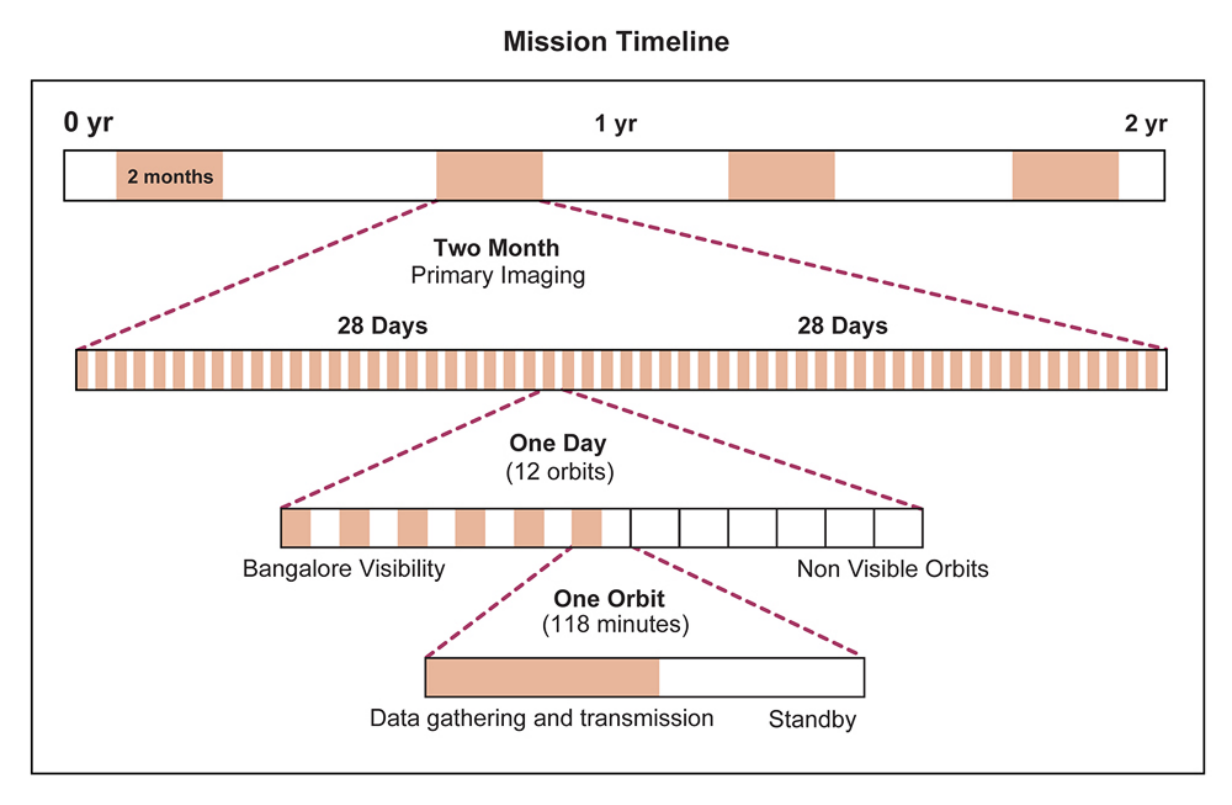
- Spectral Coverage:
  - Target: 446-3000 nm
- Spectral Resolution:
  - Target: 10nm
  - Global: 20 or 40 nm
- Spatial Resolution:
  - Target: 70 m/pixel
  - Global: 140 m/pixel
  - Doubled when from 200km orbit (see later discussion of operational history)



M3 Mission History

Planned vs. Actual Flight

- Planned observation time was 4 two-month optical periods defined by equatorial solar zenith of 0-45°



Planned vs. Actual Flight

- Thermal issues plagued the spacecraft as soon as it arrived at the Moon on November 8, 2008
- Lost the 1st of 2 star trackers before a single image was taken
- Extended commissioning phase was required, lasting into Jan 2009

Planned vs. Actual Flight

- The Chandrayaan-1 Mission Operations team did a fantastic job redesigning the mission in real time throughout the mission lifetime
- Despite all the challenges, we were able to meet baseline mission requirements thanks to heroic efforts on the part of Ch-1 and M3 team members
- LOLA topography data were essential for orthorectification

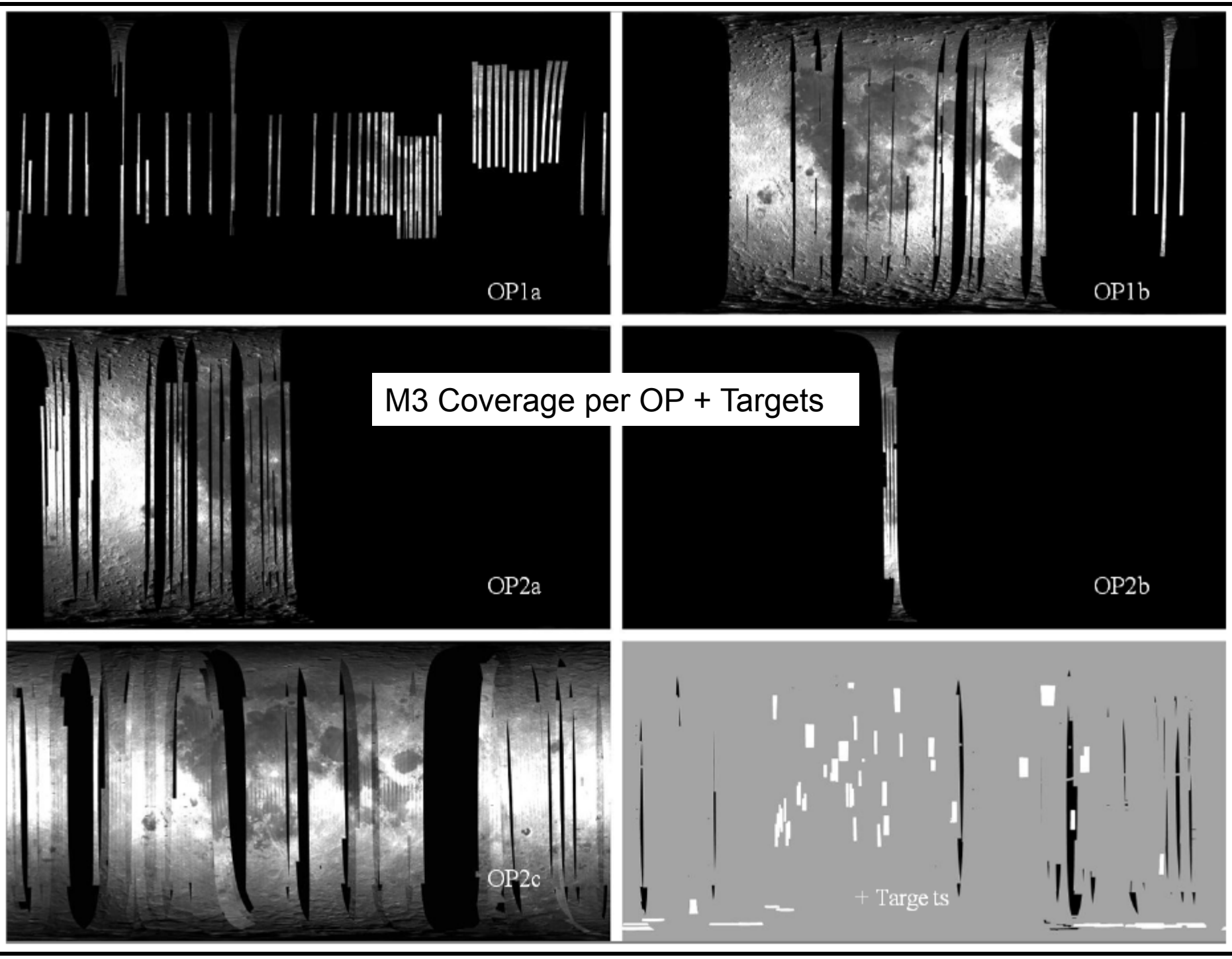
Planned vs. Actual Flight

- Impact on data:
  - Instrument was operated at less favorable viewing conditions, resulting in lower reflected surface signal and increased effects of shadows
  - The spacecraft acquired data intermittently during two optical periods
    - Almost all M3 data were acquired in reduced resolution ("Global") mode; very few optimal resolution ("Target") mode observations acquired.
    - Most of 2nd optical period taken at higher orbit (200km vs 100km) and *with no star trackers*

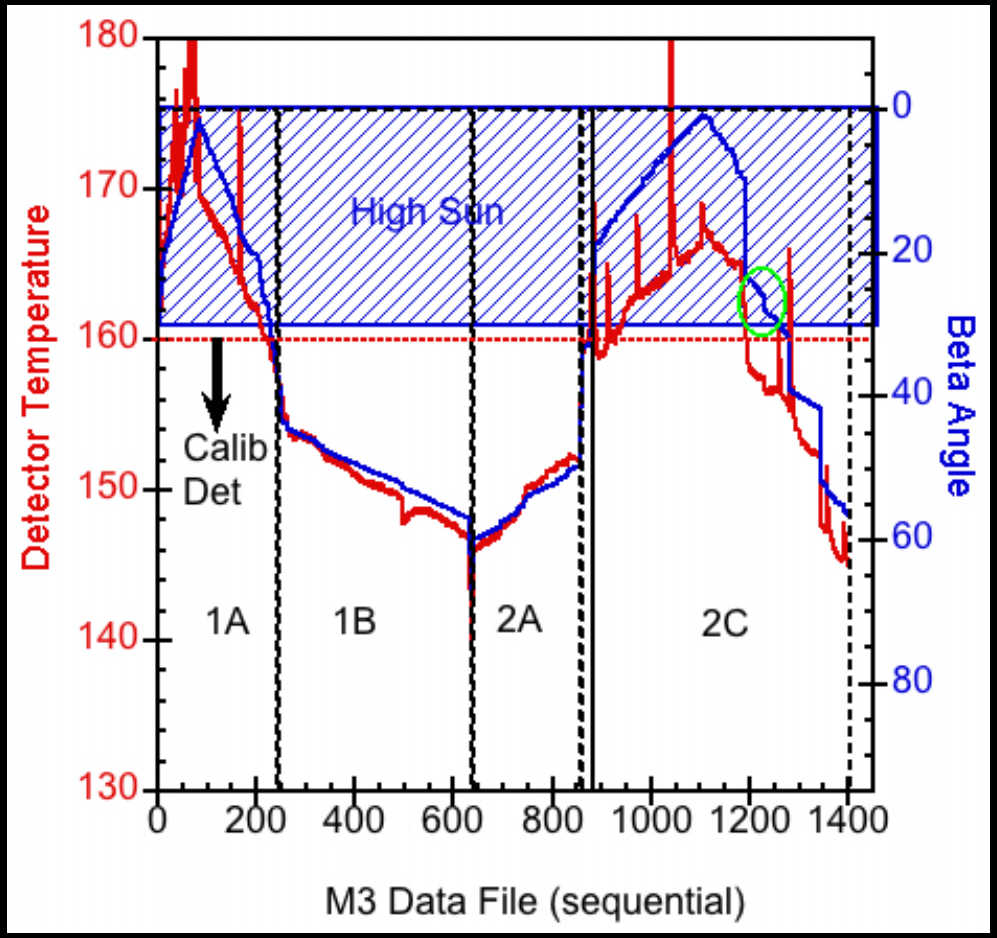
M3 Optical Periods

- M3 observed data during two optical periods, defined by favorable viewing conditions
- The team subdivided the optical periods based on data characteristics:

Period	Dates	Images	Orbit	Star Sensors	Status
OP1A	Nov 18 - Jan 24	119	100 km	1 of 2	extended commissioning
OP1B	**Jan 25 - Feb 14**	**247**	**100 km**	**1 of 2**	**operational, high solar zenith angles**
OP2A	Apr 15 - Apr 27	197	100 km	1 of 2	operational, high solar zenith angles
OP2B	May 13 - May 16	20	200 km	0 of 2	S/C emergency, orbit raised
OP2C	**May 20 - Aug 16**	**375**	**200 km**	**0 of 2**	**operational, variable conditions**


M3 Coverage per OP + Targets
OP1a
OP1b
OP2a
OP2b
OP2c
+ Targe ts

M3 Optical Periods



- Optimal low detector temperature acquisitions occurred during highest beta angles (angle between orbit plane and sun direction)

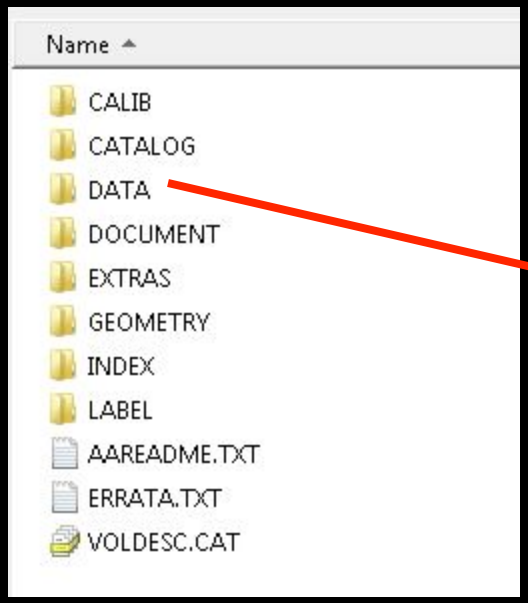
PDS Releases

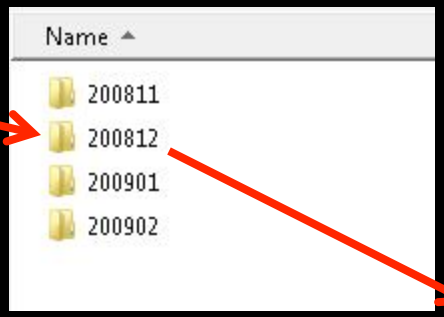
- Level 0 and Level 1B:
  - OP1 (R3, R4 calibration): June 2010
  - OP2 (R4 calibration): December 2010
- Level 2 (projected R4 calibration):
  - OP1 and OP2: June 2011

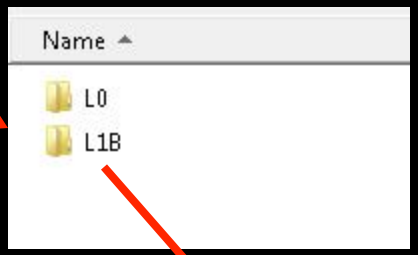
L0 = raw spacecraft data, L1b=radiance + backplanes, L2 = reflectance

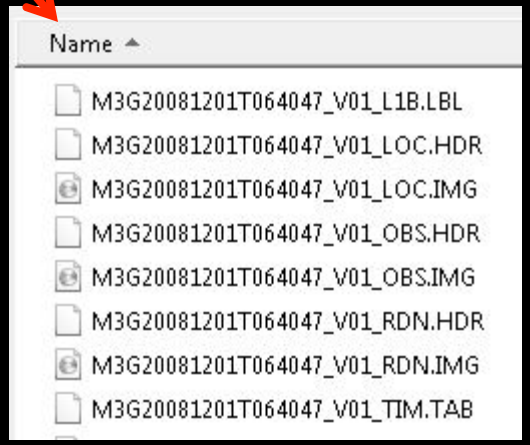
M3 File Formats/PDS Structure

PDS Directory Structure









- Standard PDS structure

M3 File Naming Convention

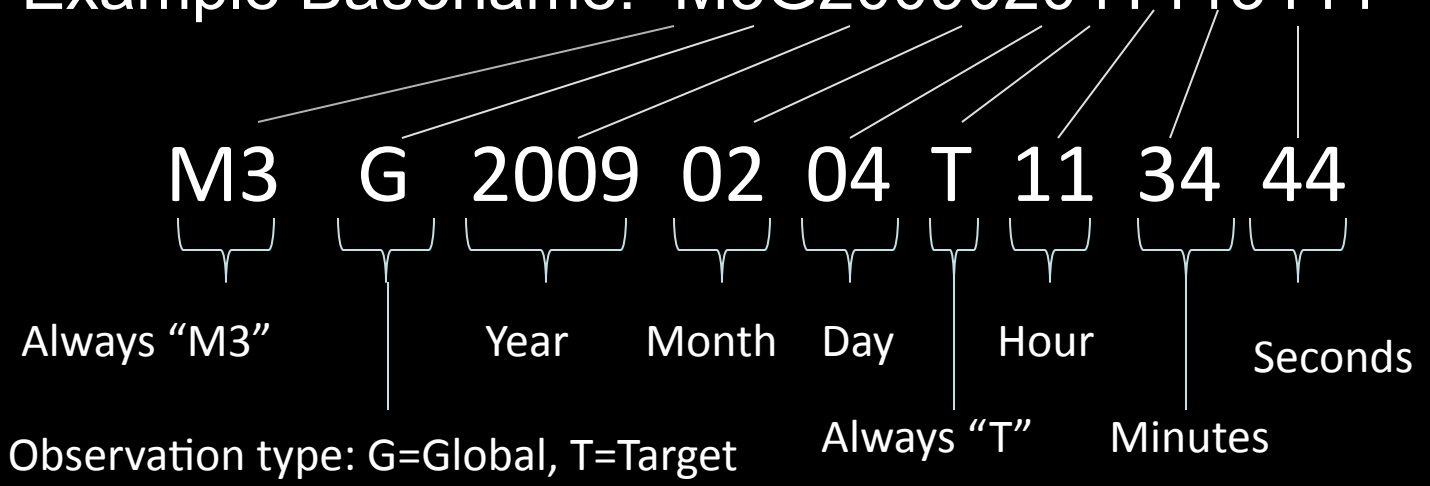
M3G20090204T113444_V01_RDN.IMG

Basename | Pipeline | Data Type | File Type

- Basename – covered next slide
- Pipeline – not used: was to be pipeline run number, but is always "V01" in PDS data
- Data type – tells you the type of information stored in the file
  - Possible values in L1B delivery:
    - L0 – raw spacecraft data
    - RDN – radiance
    - OBS – observational data (incidence, emission, phase angles, etc.)
    - LOC – location data (latitude, longitude, radius)
    - TIM – time of observation
- File Type – tells you the file format
  - Possible Values in L1B delivery:
    - IMG – raw binary image data
    - HDR – ENVI header
    - LBL – PDS label
    - TAB – tabular data stored in ASCII format

M3 File Naming Convention (cont'd)

Example Basename: M3G20090204T113444



Note: Sorting by filename is only equivalent to sorting by observation time if you do not have global and target data mixed together. If you do have a mix of the two, remove the first three characters then sort by filename to also sort by observation time.

M3 image data format

- The following applies to all M3 image data:
- Files are raw binary data (no offset)
- Interleave is BIL (line-interleaved)
- Global data have 304 samples (columns) for all image types (except L0, which has 320)
- Targeted data have 608 samples (L0 has 640)
- Number of lines (rows) is variable (determined by length of observation)
- Data type is 32-bit floating point (LOC files are 64-bit double precision floating point)
- “Backplanes” = OBS, LOC, and TIM files

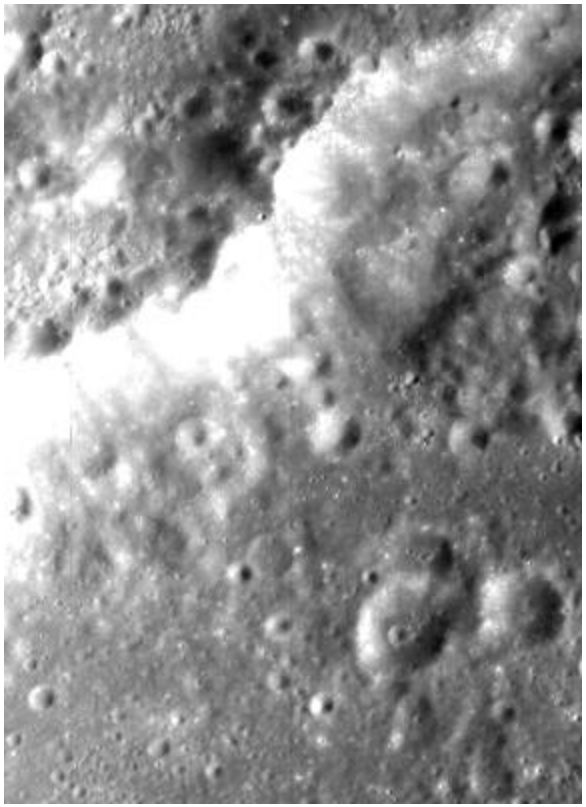
M3 Data types: L0

M3G20090126T033545_V01_L0.IMG

- L0 is raw spacecraft data, units are DN
- 320 samples which are reduced to 304 when converted to radiance
  - The 16 columns that are removed are for monitoring dark signal level and scattered light
- Each frame has a 1280-byte header
- To directly compare L0 to radiance:
  - No sample or line flip starting Nov 16 2008
  - Sample only flip starting Dec 18 2008
  - Line only flip starting Mar 14 2009
  - Sample and line flip starting Jun 18 2009

M3 Data Types: L1B RDN

M3G20090126T033545_V01_RDN.IMG



- Radiance data, units W/(m^2 Sr µm)
- Steps used to create radiance described in calibration slides
- PDS label or ENVI header can be used to open files
- ENVI Header contains:
  - Calibration steps
  - Target wavelengths (averaging for global)
  - Target FWHM
  - Dark Signal Image
  - Anomalous Detector Map
  - Flat Field Image
  - Detector Temperature
  - Beta Angle
  - Sample/Line flip code

M3 Data Types: OBS

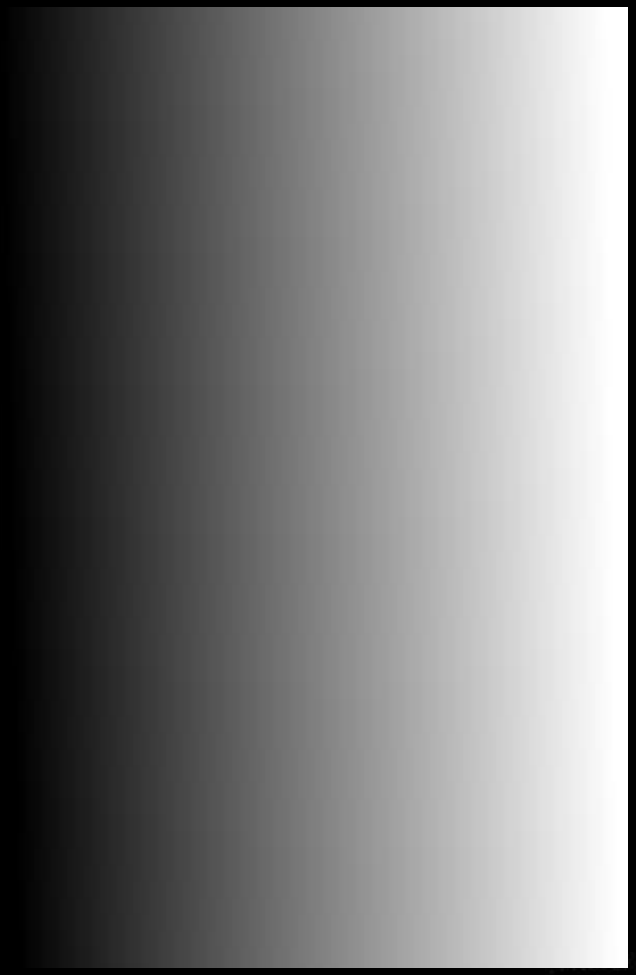
- List of bands in OBS file:
  - To-Sun Azimuth (deg)
  - To-Sun Zenith (deg)
  - To-M3 Azimuth (deg)
  - To-M3 Zenith (deg)
  - Phase (deg)
  - To-Sun Path Length (au-0.981919816030)
  - To-M3 Path Length (m)
  - Facet Slope (deg)
  - Facet Aspect (deg)
  - Facet Cos(i) (unitless)

Scene-mean to-Sun path length

- Values in the To-Sun Path Length band are the difference from the scene mean path length.

M3 Data Types: OBS

Phase angle band



Facet cos(i) angle band

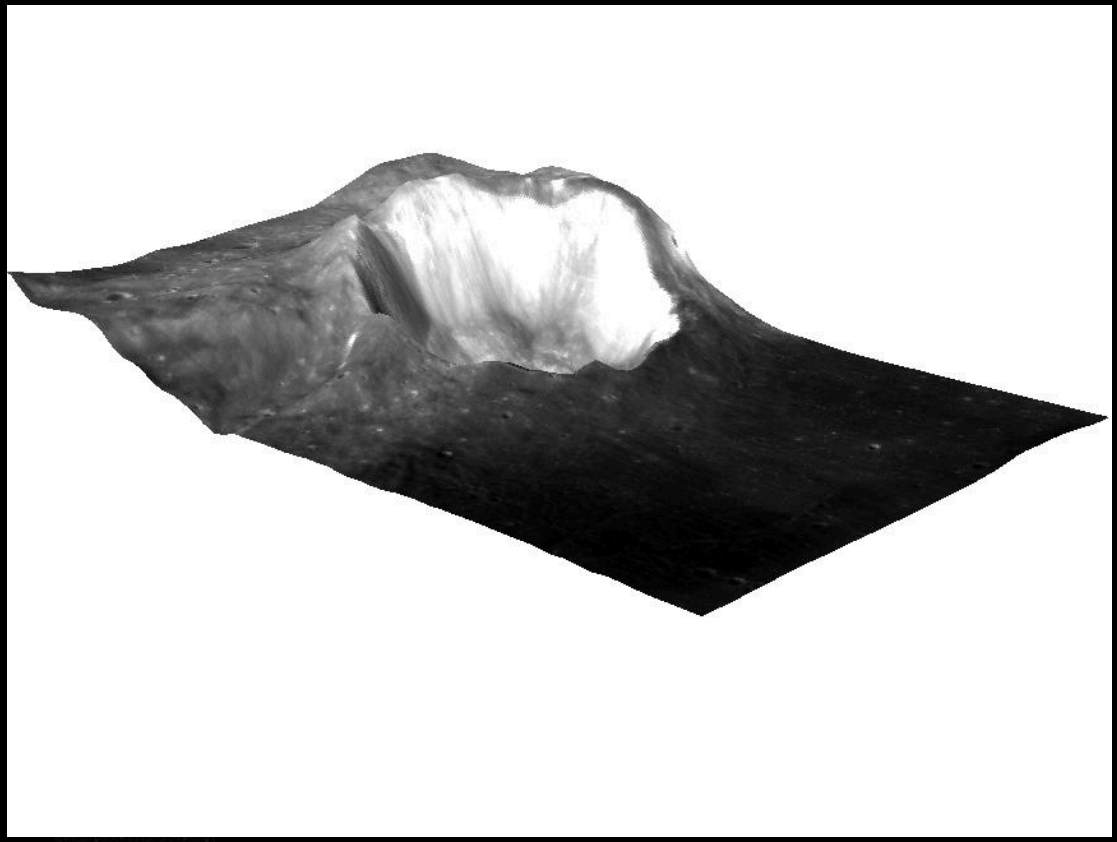
M3 Data Types: LOC

- List of channels in LOC file:
  - Longitude
  - Latitude
  - Radius
- Subtract lunar radius of 1737400 m to get difference in elevation from reference sphere
- Based on LOLA topography (see Boardman et al., in press)
- Reference frame is Moon Mean Earth Polar Axes (MOON_ME) frame

M3 Data Types: OBS

Band 3 “Radius”

750 nm albedo draped over “Radius” band



M3 Data Types: TIM

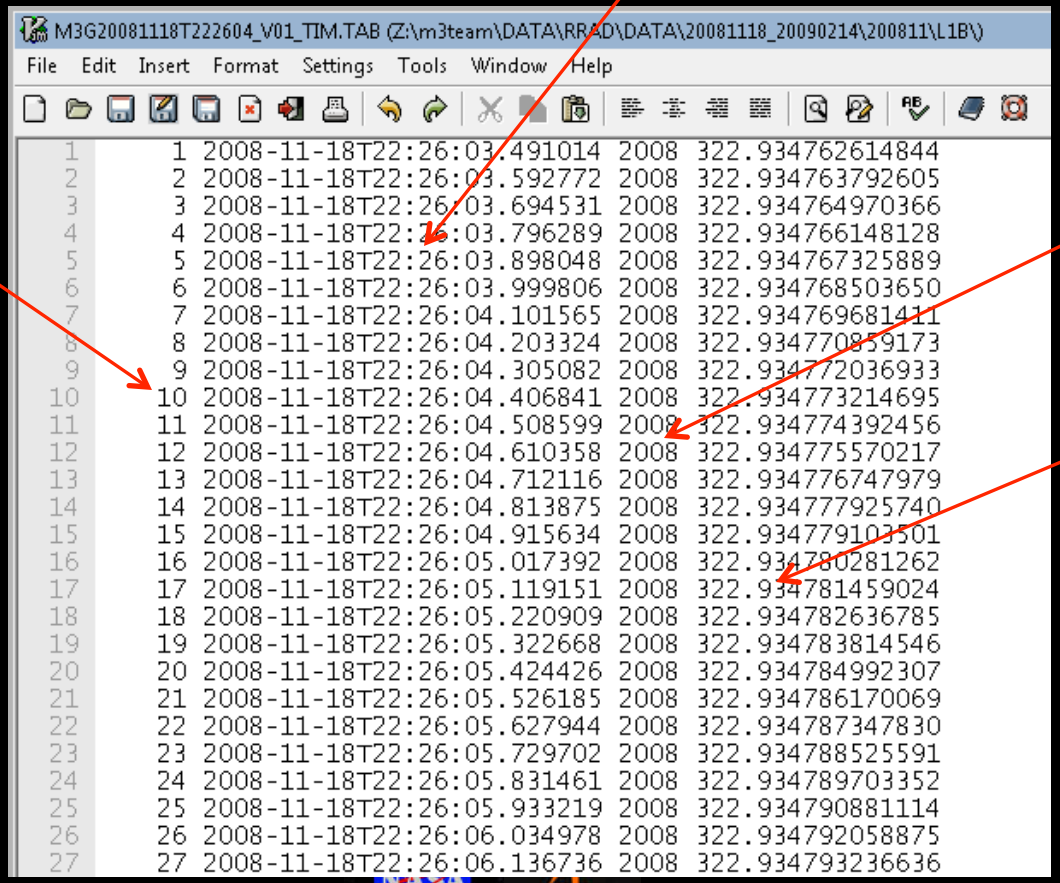
One ASCII text record per frame:

Column 2: UTC Time

Column 1: Frame Number

Column 3: Year

Column 4: Decimal Day of Year



1	1	2008-11-18T22:26:03.491014	2008	322.934762614844
2	2	2008-11-18T22:26:03.592772	2008	322.934763792605
3	3	2008-11-18T22:26:03.694531	2008	322.934764970366
4	4	2008-11-18T22:26:03.796289	2008	322.934766148128
5	5	2008-11-18T22:26:03.898048	2008	322.934767325889
6	6	2008-11-18T22:26:03.999806	2008	322.934768503650
7	7	2008-11-18T22:26:04.101565	2008	322.934769681411
8	8	2008-11-18T22:26:04.203324	2008	322.934770859173
9	9	2008-11-18T22:26:04.305082	2008	322.934772036933
10	10	2008-11-18T22:26:04.406841	2008	322.934773214695
11	11	2008-11-18T22:26:04.508599	2008	322.934774392456
12	12	2008-11-18T22:26:04.610358	2008	322.934775570217
13	13	2008-11-18T22:26:04.712116	2008	322.934776747979
14	14	2008-11-18T22:26:04.813875	2008	322.934777925740
15	15	2008-11-18T22:26:04.915634	2008	322.934779103501
16	16	2008-11-18T22:26:05.017392	2008	322.934780281262
17	17	2008-11-18T22:26:05.119151	2008	322.934781459024
18	18	2008-11-18T22:26:05.220909	2008	322.934782636785
19	19	2008-11-18T22:26:05.322668	2008	322.934783814546
20	20	2008-11-18T22:26:05.424426	2008	322.934784992307
21	21	2008-11-18T22:26:05.526185	2008	322.934786170069
22	22	2008-11-18T22:26:05.627944	2008	322.934787347830
23	23	2008-11-18T22:26:05.729702	2008	322.934788525591
24	24	2008-11-18T22:26:05.831461	2008	322.934789703352
25	25	2008-11-18T22:26:05.933219	2008	322.934790881114
26	26	2008-11-18T22:26:06.034978	2008	322.934792058875
27	27	2008-11-18T22:26:06.136736	2008	322.934793236636

Good Stuff in the PDS Directories

- CALIB
  - Record of detector temperatures, band pass functions, spectral calib. File (wavelength center positions), radiometric calibration coefficients
- DOCUMENT
  - Data Product SIS document that describes all files released to PDS down to the byte level; Archive Volume SIS describes PDS directory structure
- EXTRAS
  - Flat fields, anomalous detector element maps, quicklooks

Calibration

Converting L0 to L1 (Radiance)

- M3 Global Mode Calibrated Data version r4
- Raw image;
- Dark signal subtraction;
- Anomalous detector element interpolation;
- Interpolate filter edges c13, c50;
- Interpolate detector panel edges s81, s161, s241;
- Electronic panel ghost correction;
- Dark pedestal shift correction;
- Scattered light correction;
- Laboratory flat field;
- Image based flat field w/ photometry preserved;
- Apply radiometric calibration coefficients;
- Units (W/m^2/um/sr)

See Green et al. (under review) for more detailed description.

Basic calibration equation

$$L_{l,s,\lambda} = RCC_{\lambda}(C_{s,\lambda}(DN_{l,s,\lambda} - \overline{DS_{s,\lambda}}))$$

- L = calibrated radiance
- RCC = radiometric calibration coefficients
- C = term encompassing all correction factors (flat fields, etc.)
- DN = raw digital number
- DS = dark signal

Initial Steps of (ongoing) Level 2 Preparation

Converting Radiance to Reflectance

- Official M3 L2 Product is still under development
- Until that is available, team use an intermediate product called *I/F*

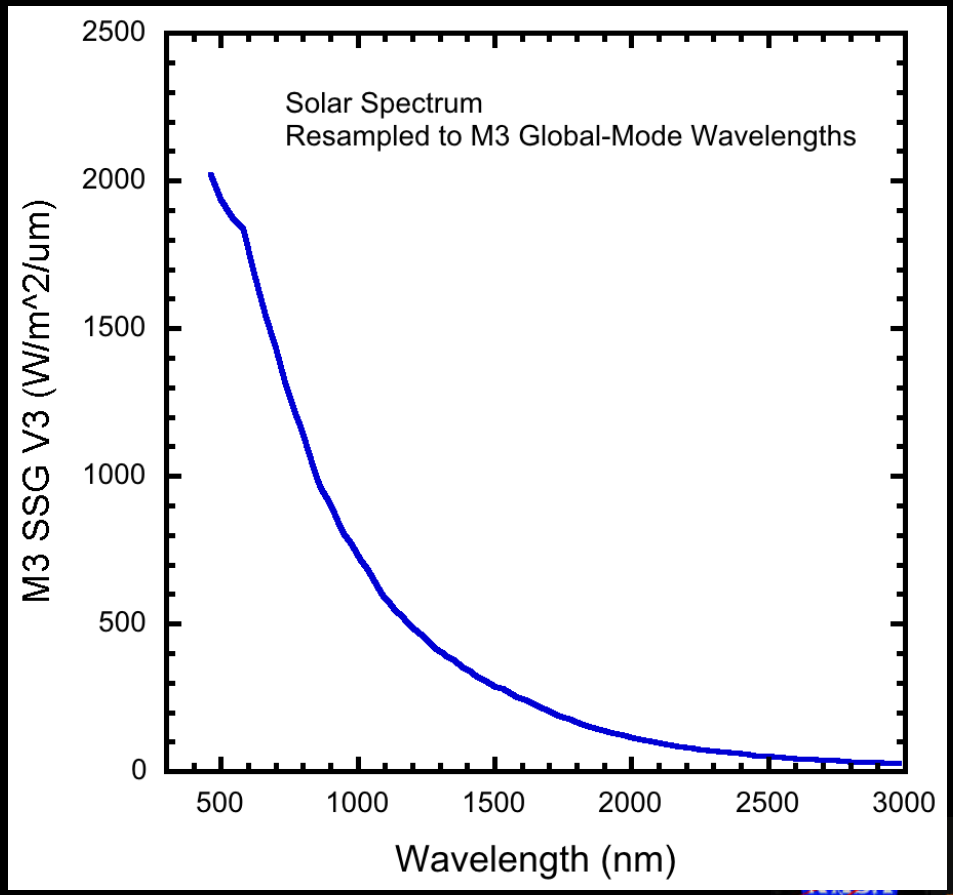
$$IoF = \frac{I\pi d^2}{F}$$

- Where:
  - I = radiance in W/m²/Sr/µm
  - F = solar flux (solar spectrum) in W/m²/µm
  - d = Moon-Sun distance in AU

Download M3 Solar Spectrum

http://m3.jpl.nasa.gov/docs/solar_spec_global85.txt

http://m3.jpl.nasa.gov/docs/solar_spec_target256.txt



- MODTRAN-based
  (See Green et al., 2010)
- Global and target resolution version can be downloaded in ASCII format from the above links
- See http://m3.jpl.nasa.gov/m3data.html for more

Download M3 Solar Spectrum

http://m3.jpl.nasa...spec_global85.

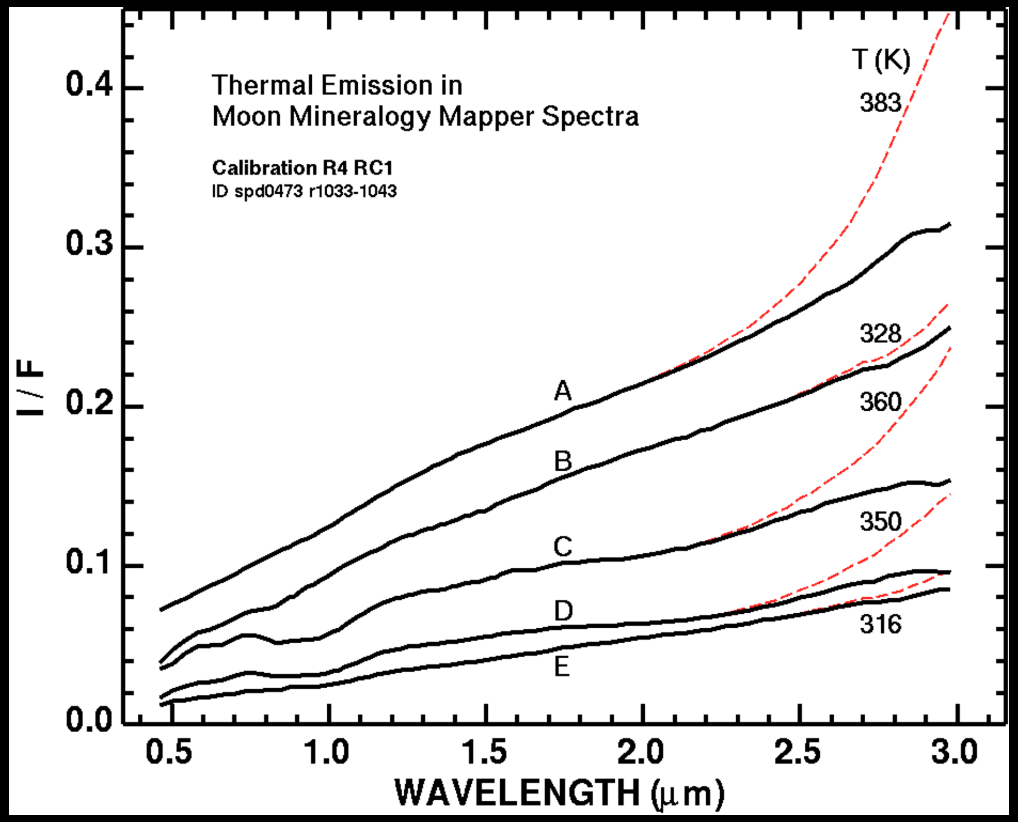
```
ENVI ASCII Plot File [Mon Nov 22 17:44:36 2010]
Column 1: Wavelength(nm)
Column 2: M3 SSG V3 (W/m^2/um)~~1
   460.989990  2022.662109
   500.920013  1934.504639
   540.840027  1875.621826
   580.765015  1833.137451
   620.689941  1689.644409
   660.609985  1550.267334
   700.537537  1428.238281
   730.479980  1324.721680
   750.440002  1271.074707
   770.400024  1216.917114
   790.364990  1162.946045
   810.330017  1107.837036
   830.290039  1053.718018
   850.250000   985.262878
   870.209961   946.577942
   890.174988   920.729126
   910.140015   879.042053
   930.099976   838.584351
```

- File is tab-delimited ASCII text
- 3 lines of header information to be skipped when importing

*Words of caution regarding M3 dataset (**R4 Calibration**)*

R4 Calibration is the version included in the June 2010 (OP1) and Dec. 2010 (OP2) Level 1 PDS data releases

Thermal emission at long wavelengths

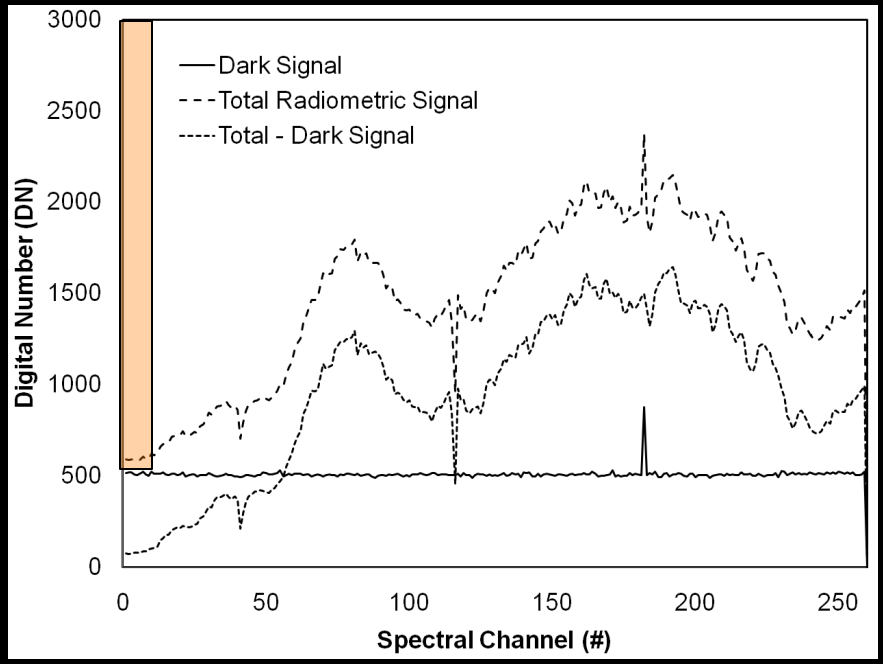


Clark et al., JGR, In Press

- M3 data contain a component of emitted thermal (black body) radiation.
- More extreme for warm/hot surfaces; more notable at long wavelengths
- Removal of thermal emission is discussed by Clark et al. (2011)

Low signal levels at short wavelengths

- The shortest wavelengths have the lowest overall signal. Given the unfortunate low lighting conditions for much of M^3 data, these channels may not be far above the dark (offset) signal, which can contribute to a range of adverse effects on M3 data.
- These wavelengths thus often contain spurious effects and should **NOT** be used in ratio images or quantitative analyses.
- *L2 data from R4 data will probably be delivered with unreliable channels set to zero. [est. below 620 nm] (but will still contain 85 spectral bands).*
  - Caution should be exercised with R4 L1B data when converting to reflectance (L1B PDS archive does not have unreliable bands set to 0!).

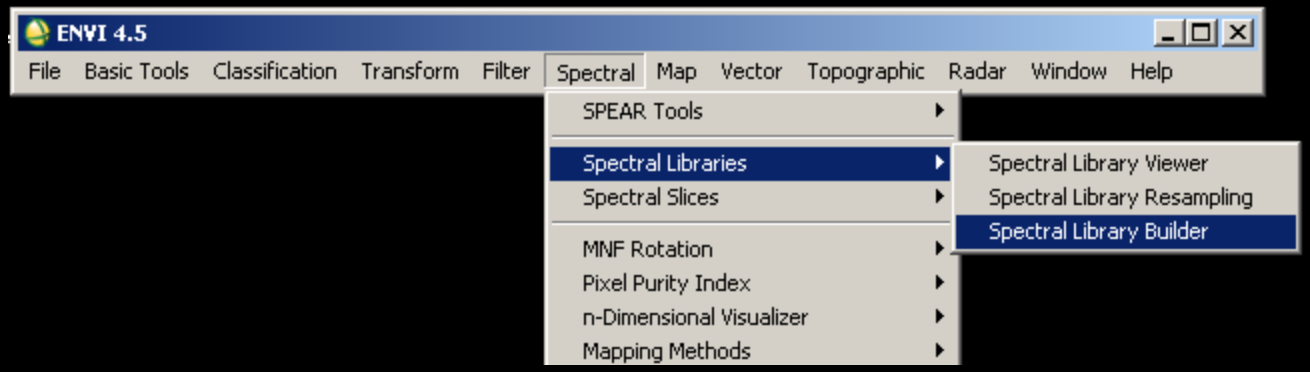


Green et al., 2011, JGR submitted

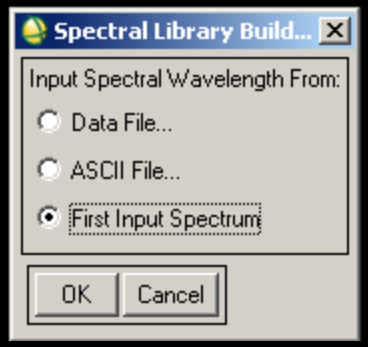
Steps to convert radiance to I/F in ENVI

Step 1: Import M3 Spectral Library

- Step 1:



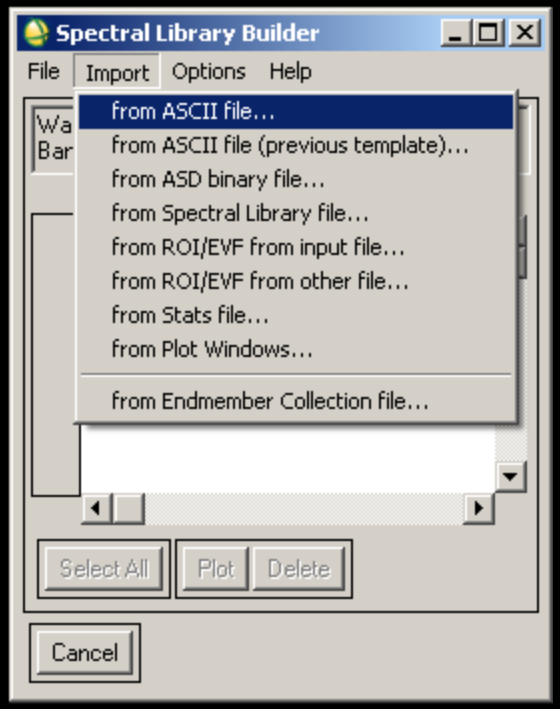
- Step 2:



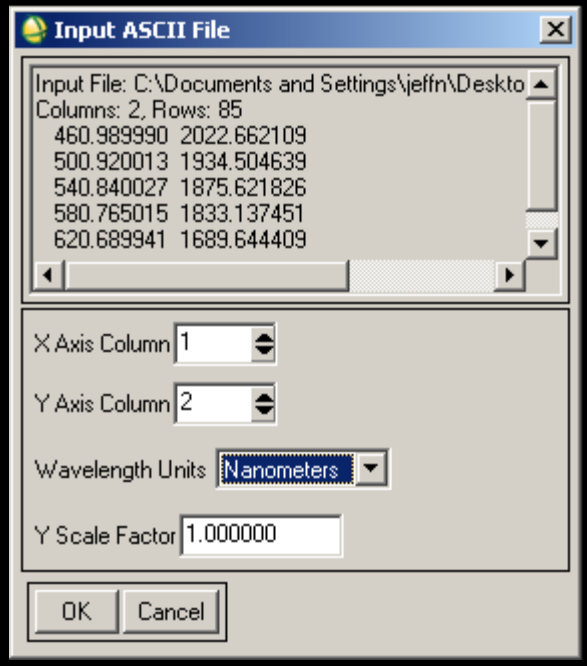
(Can also choose “ASCII File….” here but that has more steps)

Step 1: Import M3 Spectral Library

Step 3:

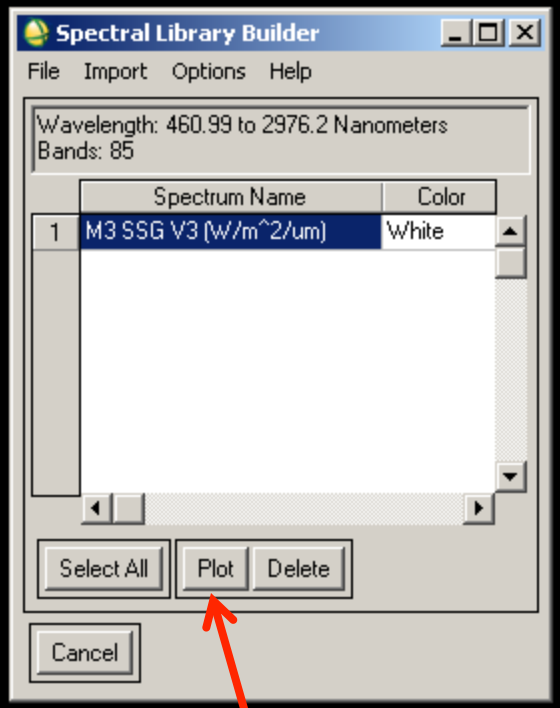


Step 4:



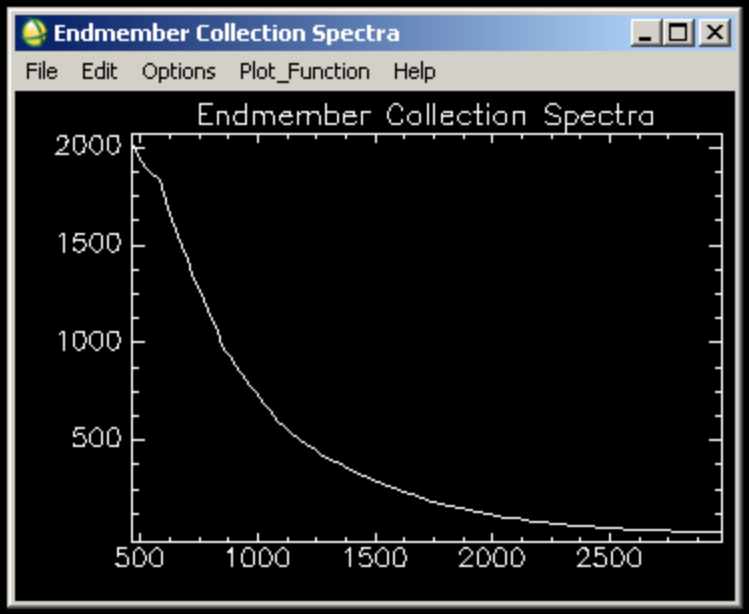
Step 1: Import M3 Spectral Library

Step 3:



Click Plot

Done!

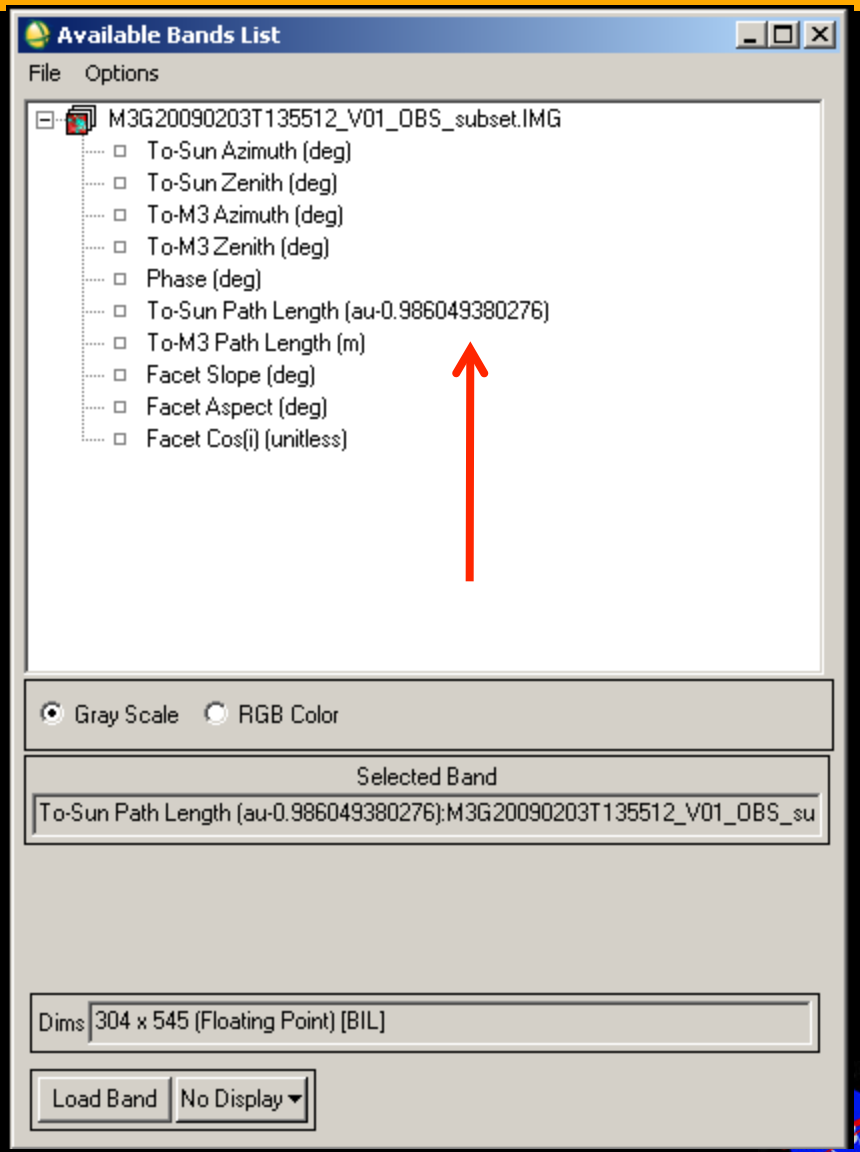


(Can save file as spectral library from File menu)

Step 2: Open Files

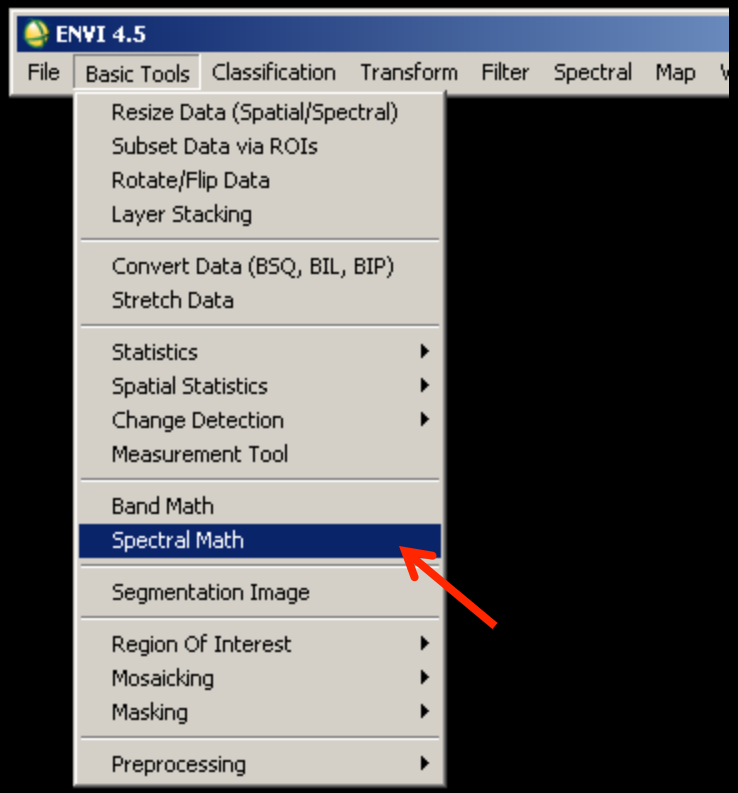
- Open radiance (RDN) file in ENVI:
  - File > Open Image File
- Open observations (OBS) file also
  - This step can be skipped if you want to use 1.0 AU for the Moon-Sun distance (~2% error)
- Open and plot the M3 solar spectrum if you have not already

Step 3: Get the Moon-Sun Distance



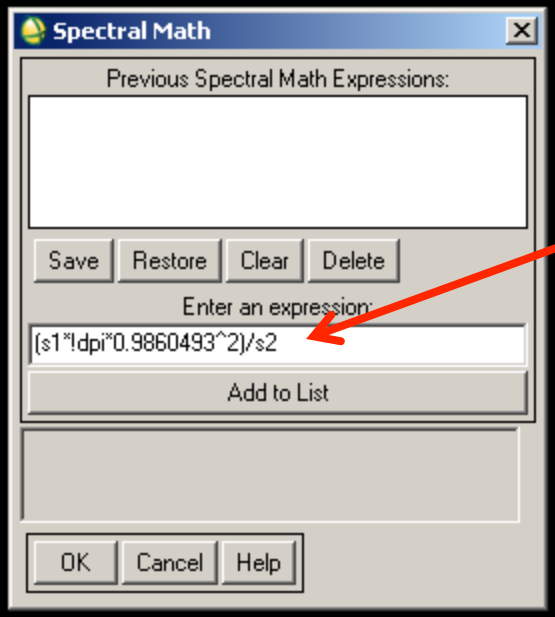
- Get mean distance from list of band names of the OBS file
- Could use per-pixel values in the To-Sun Path Length Band (band math)

Step 4: Call Spectral Math



- Select Spectral Math under Basic Tools menu (also under Spectral menu)

Step 5: Enter the expression



- Expression is:

float((s1*!dpi*0.9860493^2)/s2)

Radiance

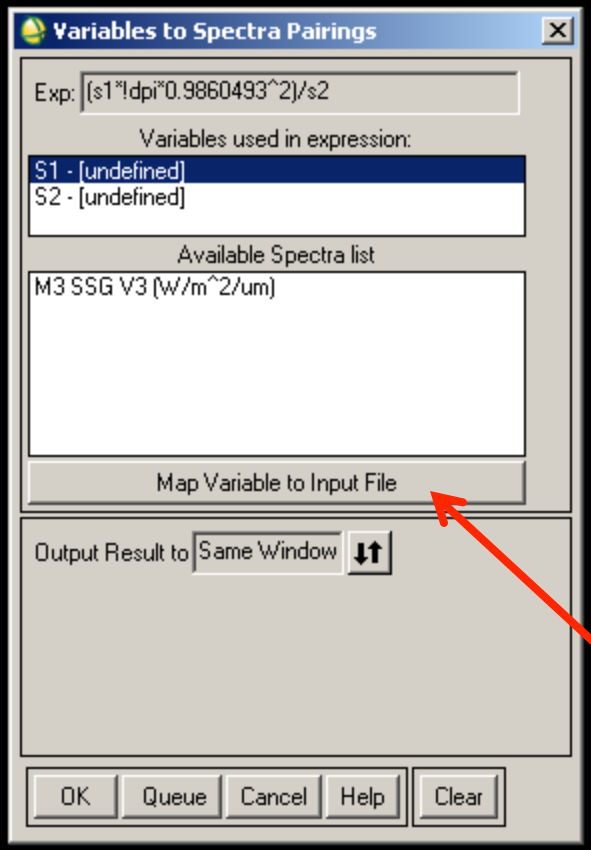
Double precision π

Moon-Sun distance squared; variable per file…

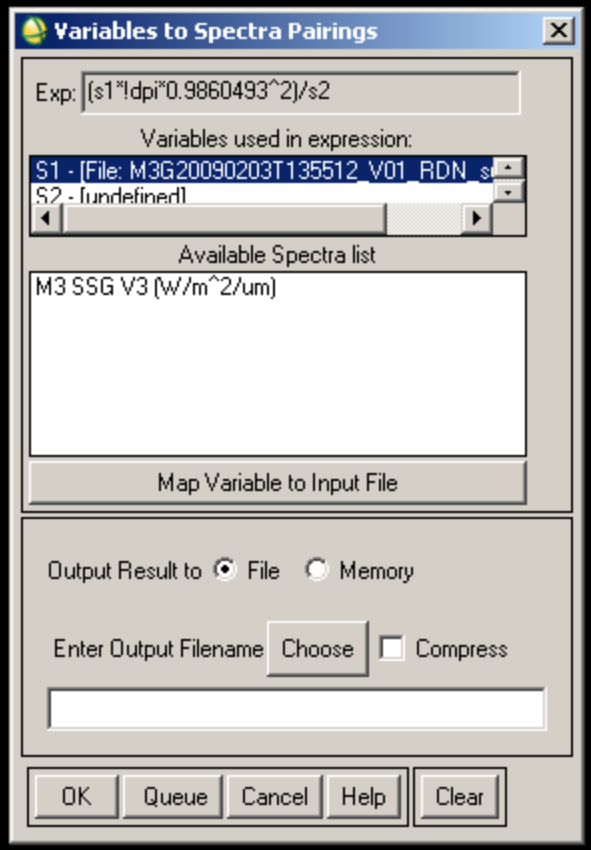
Solar Spectrum

Step 6: Define s1

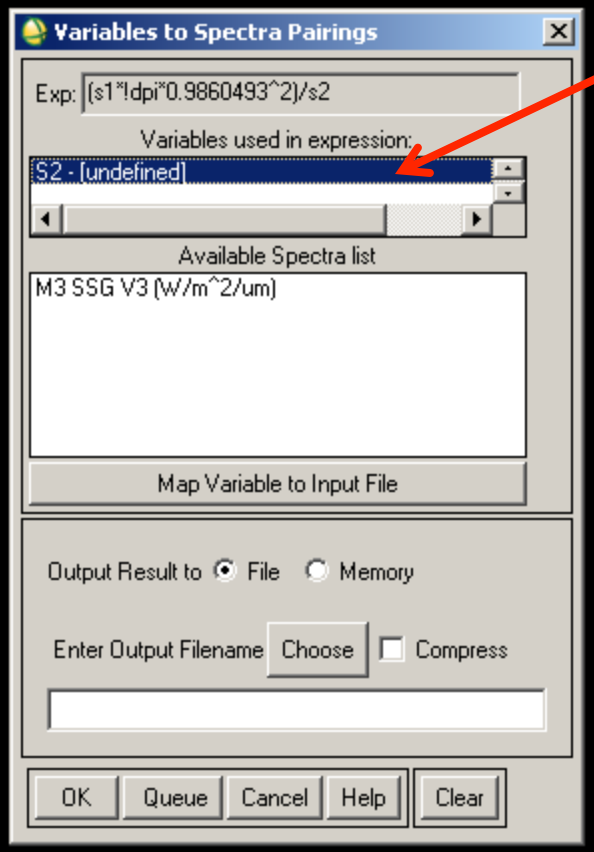
Click “Map Variable to Input File” and select your radiance (RDN) file



Should end up with this:

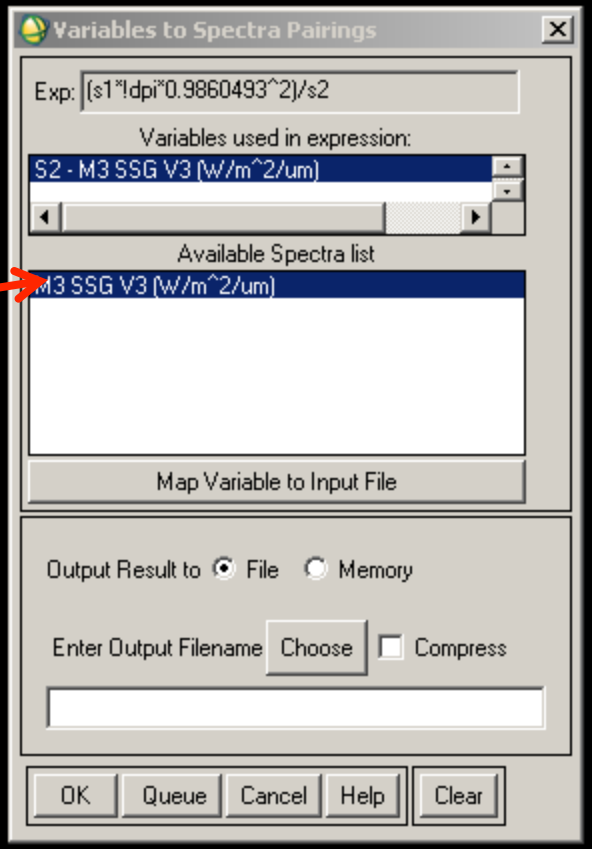


Step 7: Define s2

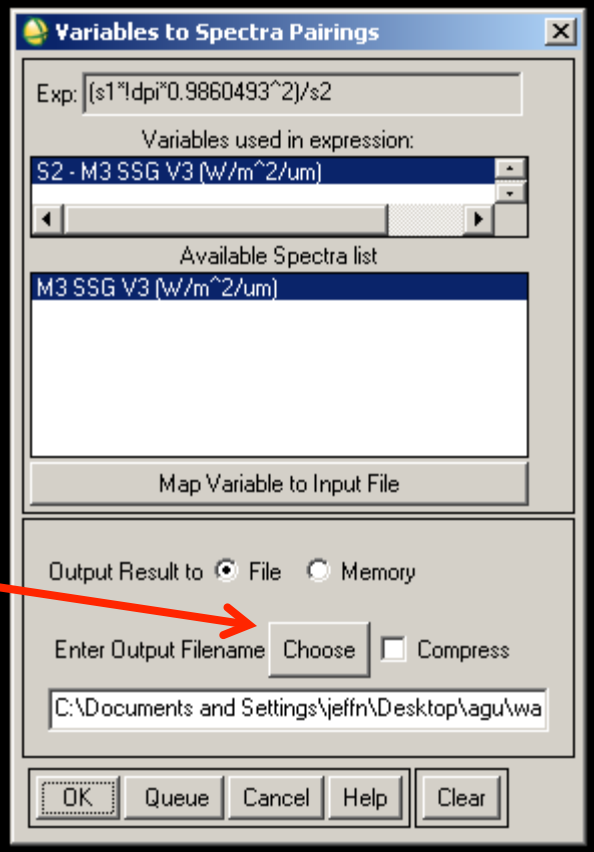


First Click

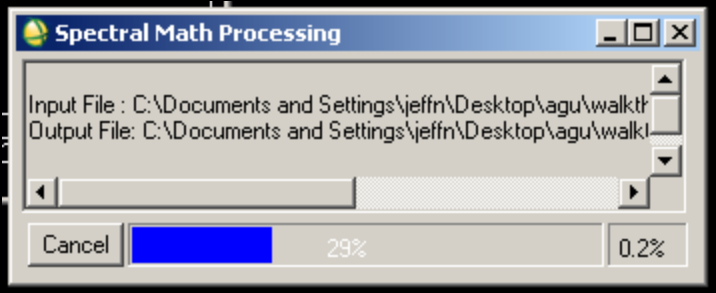
Second Click



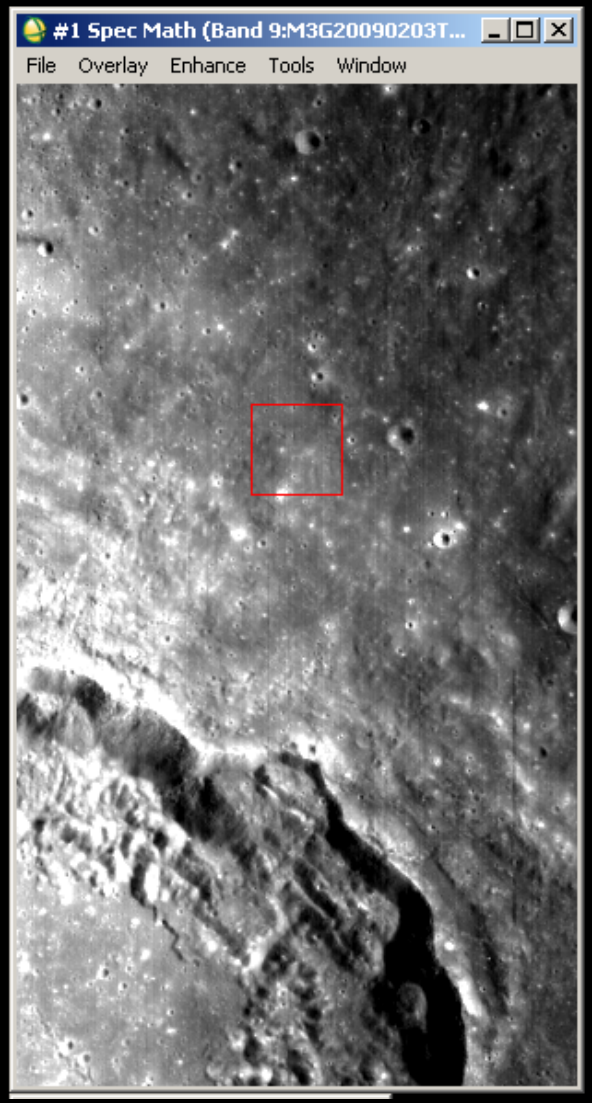
Step 8: Choose Output File

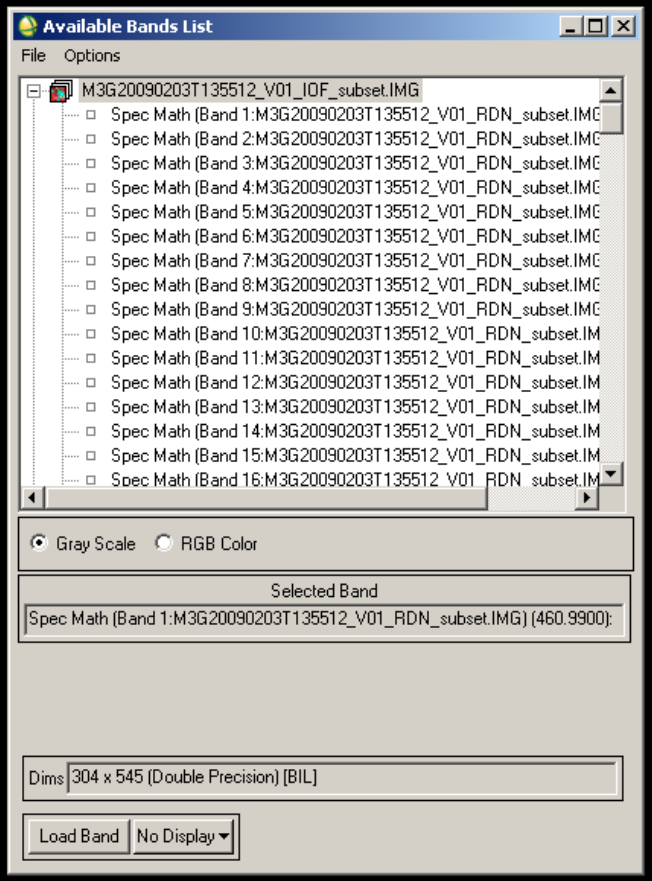


- Then click “OK” and ENVI goes to work…



Last Step: Enjoy!





Check your work!

- Example radiance, observations, and I/F file posted to M3 website so that you can make sure you get the same answer we do:
- http://m3.jpl.nasa.gov/m3data.html
- Filename:
  M3_TestSubsetCube_M3G20090203T135512_R4.zip